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Safety of Level 4 Autonomous Vehicle: Still Human in the Loop

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Abstract

When Autonomous vehicles have come into the limelight both in the field of practical use and in the research domain, the continuous complexity of shared decision-making, liability, and ethics in a human-autonomy team is still finding ways to be resolved. Especially in level 4 autonomous vehicles, when almost everything is to be done by the autonomous system, the role of humans needs to be more structured. In this paper, we discuss the safety concern of a level 4 autonomous vehicle, keeping the human users in focus. We identify the critical safety concerns that can occur in a level 4 autonomous vehicle due to the autonomous system's error and how humans in and out of the loop can play a role there. We have three major topics discussed in this paper regarding the safety of level 4 autonomous vehicles: 1) identification of major safety issues of a level 4 autonomous vehicle, where we discuss the safety issue that can arise and whether the human user's invention can prevent the hazard, 2) discussion of the factors which needs to be considered to build an efficient Human-Machine Interface, through which the human user will be in the loop of the operation of the autonomous system and can play a crucial role to prevent potential safety hazard caused by the autonomous system error, 3) potential use of brain-machine interface technology to provide more robustness to the human-autonomy teaming in an autonomous vehicle context.

Keywords

Autonomous Vehicle (AV), Level 4, Safety, Human-Machine Interface, Brain-Machine Interface (BCI)

1. Introduction

When it comes to an autonomous vehicle, which is supposed to run on a busy road alongside humans, the safety concerns not only address the technical errors but also bring up the questions of liability and interactions with humans. Autonomous vehicles are comprised of intricate electronic systems, which work successfully with a high level of synchronization with advanced software and a super-alert sensing system compatible with the outside chaotic world. When we are considering level 4 autonomous vehicles, it comes with both sides of human interaction; that is, inside the human safety driver as well as the outside fellow road-runners.

As the technology of autonomous vehicles is developing and starts running on roads, safety concerns are being addressed as more and more important. Yet, the safety aspects of such an advanced technology are not fully investigated because it has not run enough miles in practical scenarios to provide researchers with enough scenarios to assess every situation. We mention every situation; it encompasses all the situations wherever safety is associated, including who is supposed to incorporate safety measures in design, safety drivers: how the safety drivers process the autonomous vehicles' behavior, especially in an adverse scenario, the passengers, who are not the safety drivers, but still the stakeholders will face consequences if any safety issue happens, the owners, who are going to face loss, the outside fellow road-runners, who needs to learn how to deal with an autonomous vehicle's approach and so many more.

As per the SAE standard (SAE J3016 2021), the autonomous vehicle can be categorized into five levels; the level 4 AV can run fully autonomously and eliminates the role of the traditional driver when the system is engaged. It is even said that the passenger can take a nap while the level 4 AV system is engaged. But still, the passenger is able to intervene and take over the AV system if he feels needed. So, the level 4 AV can be a conditional mode by current description, where the passenger or human user can set the system for a pre-determined route in a limited territory and when needed, can resume driving. On the website of the United States Department of Transportation (NHTSA 2023), it is mentioned that it can also operate in limited service areas. Humans are to intervene in the driving task if they only feel the need or based on an alert generated by the system. So, even if the level 4 vehicle is supposed to operate by the system fully, we can see that there is a human still in the picture, and it probably can play a role when the system fails and 'alerts' for the human intervention. Apart from the human safety driver/passenger, there will also be humans (and other lives) in the environment where the AV operates. So, we can see for an autonomous vehicle's safety domain, humans can be in three different circumstances, as shown in Figure 1.

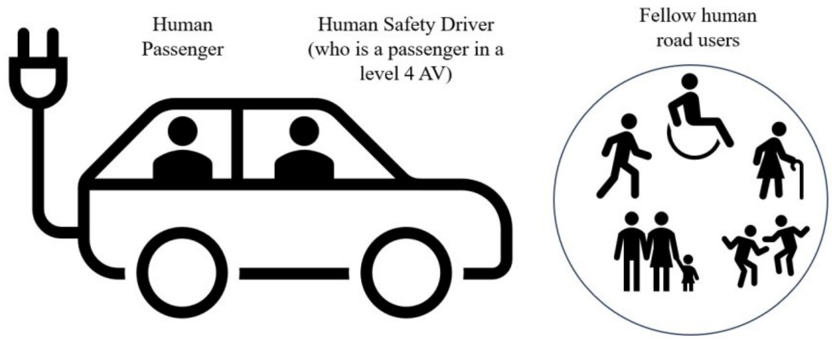

Figure 1. Three human domains in a level 4 autonomous vehicle safety concern

In this research, we focus on the safety concerns of level 4 autonomous vehicles and address them from a human side rather than a system failure side. We structured our knowledge based on previous research literature and sorted out the safety concerns that are specifically critical for level 4 autonomous cars as humans can still be a part of the operation of a level 4 autonomous vehicle, even though on an 'on-alert' basis, we also aim to address humanmachine interaction factors which would be crucial for designing such an autonomous car. As the technique of using human brain signals is getting advanced at a really fast pace, we are also considering the Brain Computer Interface (BCI) as a potential technique to incorporate in autonomous vehicles to improve agility and human-machine teaming.

1.1 Objectives

Even though the level 4 AV eliminates the role of a human driver when the system is engaged, still the vehicle (having a level 4 AV system in it) is not fully autonomous in the overall picture, which means the level 4 AV mode can run when the human permits and human can decide to take over when wants. Thus, if there is still a human being in the loop who will be able to intervene in the driving task, we can consider this human role both as a challenge and an opportunity. The challenge is, as the human is not supposed to monitor the driving operation, how and when s/he is supposed to intervene, and if the human is to respond only upon the 'alert' of the system, how is the system going to raise the concern? And how does the human know that the system is asking for the intervention? Also, this little role of humans raises the question of liability of hazard, which is already hovering over the question of running the autonomous vehicle on the road. On the other hand, we are considering the role of the human as an opportunity. By incorporating a properly designed Human-AV Interface, we may be able to strengthen the safety of the level 4 AV and eventually maybe eliminate the limitation of "operating in a limited area."

Therefore, considering the human role in the level 4 AV, we can describe the objective of this article in three parts:
1)Identify critical safety concerns of a level 4 autonomous vehicle; for this part, we actually took help from previous literature.
2)Discuss Human Machine Interface issues for a level 4 autonomous vehicle.
3) discuss the potential of incorporating the Brain-Computer Interface technique for the safety driver by presenting a preliminary study of neural signals.

2. Literature Review

In this section, we will discuss the research literature concerning the safety of autonomous vehicles, as our intention is to identify those critical for level 4. We will also go through how researchers are considering Human Factors as a safety concern for designing an autonomous vehicle and how they are still applicable for a level 4 vehicle. At last, we will go through the literature on Brain-Computer Interface (BCI) to assess the potential of incorporating this novel technology in an autonomous vehicle.

Whenever it comes to the Safety concerns of an Autonomous Vehicle (AV), it is still mostly focused on the failure of the system. As described by the ISO 26262 standard (ISO 26262 2018), it covers functional safety, which is related to systematic failure (either Hardware or Software) or random failure (Mariani 2018). As per the performance observation of AV based on the disengagement of the system of the driver and accident rate (Wang et al. 2020), along the over 3.7 million miles test-drive in the timeline from 2014 to 2018, it is found that the system was taken over by drivers frequently and the frequency of disengagement varies across manufacturers of the AV. Also, 128 accidents of that time range were investigated, and found that 63% of them were caused when the vehicle was running in autonomous mode. Curiously, a very small fraction (6%) of those accidents were actually directly related to AV's fault, whereas 94% of them were indirectly initiated by the other parties, i.e., fellow road users (Wang et al., 2020). Therefore, we can say that while ensuring proper functions of hardware and software are the topmost priority, even ensuring them 100% (which is impossible) would reduce the accidents by a very minimal fraction in the above statistical scenario. The accidents caused by AV can be majorly categorized into three types:

i) Perception error: The perception layer or module of an AV acts as the sensing system, like human eyes and ears, that collects the data from the environment by multiple sensing devices, such as Camera, LiDAR, RADAR, GPS, IMU, etc., and sends to the decision unit (Huang et al. 2013). The error of the perception module may hamper due to malfunction of any of the multiple hardware, sensing units, software, or communication units and consequently will hamper the decision-making of the system and thus may lead to hazards and accidents.

ii) Decision error: The decision module processes the information intercepted from the perception module, with the programs and software instilled in it, and sends commands to the action unit (Ha et al., 2020; Huang et al., 2016). Any decision error may lead to wrong action, e.g., unintended acceleration, wrong turn, turning at the wrong angle, running over obstacles, and many more (González et al. 2015)

iii) Action error: After receiving commands from the decision module, the action module will proceed to control the mechanical units, such as the steering wheel, throttle, brake, etc. (Fényes et al. 2019); similar to the conventional driving system, the action error may be caused by mechanical unit failures and lead to hazard.

In order to use the opportunity of a human presence, the researchers are striving to develop a Human Machine Interface (HMI), which will be apt for teaming with an autonomous vehicle. Naujoks et al. (2018) developed a framework for HMI based on SAE (Society of Automotive Engineers) guidelines and taxonomies and recommended much-needed testing methods to verify the HMI against the outlines of the National Highway Traffic Safety Administration's Federal Automated Vehicles policy. As per the investigation of AV performance (Wang et al., 2020), we can understand that a major portion of road accidents indirectly comes from fellow road users. So, the researchers were also looking for the opportunity to improve in that aspect and looking for ways to establish successful communication between AV and external road users. Dey et al. (2020) proposed a guideline for external HMI with 18-item taxonomies capturing the physical and functional features of an external HMI and systematically categorized 70 concepts for this purpose. De Clercq et al. (2019) also emphasize the effect of eHMI on the pedestrians' crossing intention.

In our paper, besides discussing the human factors in a level 4 AV scenario and the necessity of efficient Human Machine Interfaces to ensure safety, we would also like to consider a new potential, that is, incorporating BCI (Brain Computer Interface) technologies with the AV system. The BCI technology collects brain signals and uses them directly to control some external machines. We specifically find this opportunity suitable for Level 4 AV because, in Level 4 AV, human intervention is not needed, and for BCI technology, human external limb usage is not needed. So we are considering level 4 AV as a great opportunity when human users will not need to intervene physically even when 'asked' (level 3 AV) or 'alerted' (level 4 AV)and can be directed just by brain signal. And that will be a great assistive technology for vulnerable people. Neural signal analysis has progressed rapidly in recent years. It is being used to understand complex human behavior, such as intuition, decision-making (Firoz and Seong 2023b), as well as to control machines.

3. Critical Safety Concerns of Level 4 AV

Why level 4 AV is so critical? We find level 4 AV is critical because there is still the human in the loop in the AV, which leads to several dilemmas.

i) **The liability question.** For level 0 to level 3 AV, the human is supposed to monitor the driving task. Thus, the human driver is clearly liable for any driving action. For level 5 AV, the liability is totally the system as the human is nowhere in the authority chain. But for level 4, the human is there but not supposed to supervise the driving task actively. Again, the human has the ability to control the AV, which draws a fine grey line between the liability of humans and the AV system. In case any accident happens, shall we consider that the human was able to control the AV and avoid the situation?

ii) **What the human should do**. When the human is able to control the AV, what attitude should s/he bear? Totally forget that s/he is in a car? Or just a mild alert situation? What kind of alert and monitoring system is available for humans?

iii) **When and how the system would generate an alert.** The level 4 AV offers an opportunity for humans to intervene in the driving task. In case the system wants the human to take over, what kind of signal it provides?

The above questions should be considered while designing a level 4 autonomous vehicle. Also, a guideline generation is required for level 4 AV focusing on human behavior and human-machine interface.

4. Opportunity of Level 4 AV using proper HMI

As we mentioned earlier, the mere presence of human controllability in level 4 automation raises great challenges as well as offers immense opportunity. In this paper, we discuss how the installation of a proper Human Machine Interface can develop level 4 AV into a cutting-edge practical solution to those challenges. As level 4 AV is defined that it will not be supervised by humans when the system is engaged, the HMI is required only to prevent the hazard in case of any error/failure caused by the system. That makes the difference between the HMI of a level 2/3 AV and a level 4 AV. The overall human-AV interface of a level 4 AV must be designed in such a way that it does not interfere with the comfort of the human passengers. We propose an overall human-AV interface having four types of HMI.

i) The main "dashboard", which will present the overall vehicle performance, including the information as shown in the traditional car dashboard, as well as the approach and intention of the AV systems. This is the main Human Machine Interface, which is also the Human-Computer Interface through which the human gets the information about the computerized AV system. In Figure 2, this kind of HMI is referred to as a HMI1. To design this type of HMI, the seven principles of Universal design can be followed. Also, there are numerous principles, strategies, and studies about how to design an efficient human computer design.

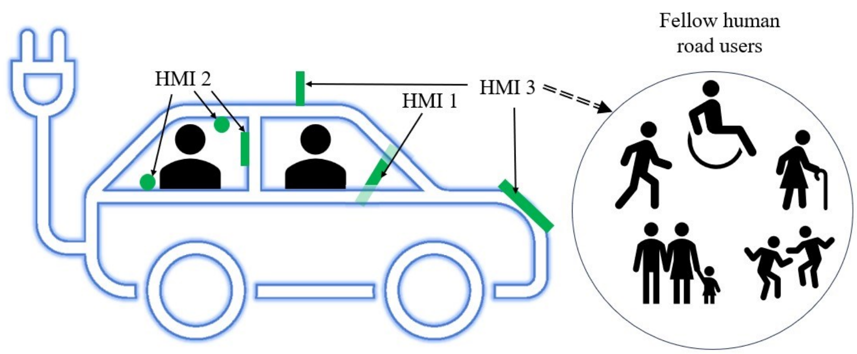

Figure 2. Schematic position of proposed HMIs (green colored) and their interaction domain of humans All the designers need to do is follow them in a level 4 AV framework. For that, in this paper, we recommend considering the following:

- Avoid information overload: The presentation of too much information at once can overwhelm the passenger(s), and thus the critical information may get overlooked.
- Strategic presentation of performance and AV status information. The system must be designed in a way that it can make decisions about what information will be useful to the passenger(s) in a very moment.
- Present the intention of the AV system. The intention of the AV must be presented on the dashboard. It will help the passenger to decide whether to intervene if such a situation happens. As an example, if the vehicle fails to detect any obstacle and thus decides to overrun, the intention will be presented as "go forward" instead of "vehicle is stopping." Then the passenger(s) will know that s/he must intervene to stop, and if the AV shows the intention as "vehicle is stopping," the passenger(s) may stay inactive. This is a very straightforward example. Detailed investigation on how to present the intention and how human behavior is expected is required.
- Present alert about minor errors/malfunctions. Just like traditional cars, minor errors or malfunctions must be presented on the dashboard. Only this is a level 4 AV, and the system is much more intricate; therefore, the system must be designed in such a way that the alerts can be presented efficiently as per their gravity. As an example, if one side camera (we are assuming that the camera puts a little support in overall perception, for example's sake) fails, it may not be a high-level safety issue but still should be presented on the dashboard. But if all the cameras and LiDARs fail at the same time, the situation is much more dangerous, and thus the alert must be presented in such a manner as to get the passenger(s)' immediate attention.

ii) Besides the main dashboard, we suggest instilling more HMI inside the vehicle. We identify it as a recommendation specifically needed for level 4 AV, as all the humans inside are considered passengers, and there would be no driver in charge of supervision. Therefore, the alerting system should address all the passengers so that in case of need, anyone in the car can take action. This type of HMI is shown as the HMI2 in Figure 2, as we are considering it as the secondary type of HMI for internal human passengers. As this is a level 4 AV, the human is not supposed to supervise the driving task. That is why we propose to design the system in such a way that it can provide alerts in a manner that will not interfere with the passengers' comfort but at the same time be able to keep them updated about the surroundings. So, the passengers have to maintain only a minimum level of alertness, similar to sitting on a park bench or lazy walking on a calm pavement. As an example, we can think of an audio alert from the right side of the car when a pedestrian is too close to the right side of the AV. Now, what would be the sound level of how many alerting systems will be installed? It needs further investigation from the perspective of human behavior analysis, the effectiveness of alerts, and manufacturers' costs and benefits.

iii) The external HMI, which will help Av to maintain communication with the external humans. Communication error is considered a potentially important factor when the AV is fully functioning along the streets. Interpersonal communication between the human driver and other fellow road users is a vital component for avoiding accidents (Stanciu et al., 2018). Road users communicate with each other to coordinate movements by exchanging gestures, facial expressions, eye contact, etc. and thus contribute to ensuring road safety, which will be absent when there is no human driver paying attention in a level 4 AV (Wang, K. et al., 2020). So in order to adapt to this human-centric behavior to operate in a human-centric environment, there should be an external HMI that will declare its status and intention as well as be able to read the other road users' intentions by monitoring body language.

iv) The emergency 'human' decision interface. The above-discussed two interfaces are for the internal human passengers to receive information about the vehicles' performance, actions, and surroundings. Another type of interface is also needed that will receive the human's decision on behalf of the system and convey it to the controller unit to act upon that. We can think of an emergency stop button as an example. Will there be only one button or several buttons so that any passenger can act? Will the passenger need to reach for the button, or will they be placed in places readily available? As level 4 AV is not supposed to have an active driver, it is a matter of further investigation of how the role of the passengers will be determined.

5. Assessment of the potential of incorporating BCI in a level 4 AV

In this paper, we are considering the potential of the BCI technique to be instilled in a level 4 AV. We propose that the incorporation of BCI technology can ensure the full benefit of a level 4 AV, where human interaction is not required all the time, but when needed, humans can act fast without literally moving a finger. It will also be able to act as an assistive technology for disabled people, where the external limb is not needed to control the vehicle in an emergency situation. For this purpose, we present a preliminary study of a binary decision, where we collected the neural signal during binary decision-making. We found that the neural signal of a binary decision based on visually presented information is distinguishable with 94% accuracy, and thus we are hopeful that the major decisions to be made by humans in a level 4 AV, such as "stop" or "continue to go" will also be distinguishable from neural signal.

5.1 Methods

In this preliminary study of binary decision-making, we implemented a modified Artificial Grammar Learning Paradigm. We presented the Grammar rules, and the participants were supposed to make the decision whether the words followed those rules or not. We collected the neural signal as Electroencephalography data and employed a machine-learning classification technique. We are not detailing the experimental design here, as this is not the main focus of the article; the experimental design, methods, and instrumentation are similar as described in the work (Firoz and Seong 2023a). In this preliminary study, to emphasize the decision-making process based on visually presented data, we provided enough time to process the presented information and observed the time and neural signal classifiability.

We investigated the binary decision of choosing between "yes" (i.e., the artificial word conforms to the artificial grammar rules) and "no" (i.e., the artificial word does not conform to the artificial grammar rules). We used seven algorithms of Machine Learning to perform classification analysis to assess the distinguishability of the neural signals associated with two different decisions. The seven algorithms are KNearest Neighbour (KNN), Random Forest Classifier (RF), Decision Tree (DT), Support Vector Machine, Naïve Bayes, Logistic Regression, and Linear Discriminant Analysis.

5.2 Data Collection

Data is collected from 3 participants, as EEG data through 30 channels (i.e., electrodes) in a non-invasive manner. They signed the consent form as approved by IRB. The sampling frequency is 128Hz. We did not perform any cleaning or pre-processing to reduce the calculation cost of the system. The information about the collected data is presented in Table 1, along with the result. We considered every data point for classification and maintained equality.

5.3 Result and Interpretation

5.3.1 Numerical Results

The best average accuracy achieved is presented in Table 1 for all three participants with their individual data as well as all the 3 participants' data together. Also, the best algorithm for the specific situation is also listed here.

Table 1. Data information and Classification accuracy

	P1	P2	P3	All3Together
Gender	Male	Female	Female	NA
Age	30	27	27	NA

Total Count of "Yes" response	10	10	8	28
Total Count of "No" response	10	10	8	28
Minimum time to response (s)	3.5	1.8	1.97	NA
Total Count of Datapoints	8,192	4,600	5,040	17,832
Accuracy*	99.69%	99.78%	99.23%	99.60%
Best Algorithm	KNN	RF	KNN	KNN

*The accuracy here means the average accuracy achieved from the classification of 10-fold cross-validation, the highest of the seven classification algorithms of Machine Learning.

We can observe that the classification accuracy is over 99% for all the instances of individual and overall scenarios. This brief analysis shows that we can develop a model for binary decisions based on visually presented information using neural signals.

5.3.2 Interpretation of Result in an AV Context

From this short pilot analysis, we can develop the below hypothesis:

- The binary decision is identifiable from the neural signal by the system; hence, there is a strong probability that the decision of a human passenger to "go" and "stop" with the AV will be detectable in a similar manner. However, a deeper investigation with an adequate number of participants needs to be performed.
- Decisions made as quickly as 1.8s can be identified by the system. Thus, it will enable the system to act upon the decision without the human need to move.

6. Discussion

This study brings the discussion of the Human Factors of a level 4 AV together under one umbrella. The intention of level 4 AV is to provide comfort (reduction of stress, elimination of active driving or monitoring) and safety (by avoiding drunk driving and fatigued driving) by eliminating the requirement of human intervention. Thus, it is more advanced than the level 2 and level 3 AV. Again, it offers the opportunity for human intervention if needed. Thus, it is more viable in practical scenarios than the level 5 AV. Therefore, in this paper, we discussed factors that can use the opportunity of human presence. By providing efficient HMI, which will not bother the human, but at the same time, humans can maintain minimum alertness to be aware of circumstances, the full potential of a level 4 AV can be explored. Also, the installation of BCI technology will give the next level of advantage, where the human will not even need to move physically but rather can convey their decision to the system directly from their thoughts. The BCI technology will also offer the monitoring of the human's trust level to the system, as a neural signal of trust and distrust situation is identifiable by the system as well (Firoz et al. 2022). This will also improve the situation as the human drivers/passengers have the tendency to take over frequently. Once the system can understand the trust of humans and adjust the system's performance accordingly, the trust situation must be better.

6.1 Proposed Improvement

This study proposes a preliminary framework for using HMI in a level 4 AV so that level 4 AV can be practically run on the road along with fellow road users. Here, we discussed several domains, which are totally different in various ways, under discussion of the safety of level 4 AV. In order to reach the goal to be implemented in a practical scenario, further investigation is needed in each domain. We plan and recommend future studies as below:

- While using a level 4 AV, human passengers' behavior and mode need to be investigated to understand and monitor how much alertness they normally maintain in a level 4 AV and how much alertness is needed.
- Whether any specific training is needed to adjust to the totally driverless system and for intervention if needed
- Proper investigation is needed for the alert and monitoring system to build a system that will not interrupt the passengers' comfort but will also keep them aware of the situation.
- We consider incorporating BCI has a very strong potential for level 4 AV, but a detailed study specifically aimed at decision-making in an AV context is needed to conclude the above hypothesis.
- Also, the research for external HMI is still not robust enough. In our research study, we highlighted the importance of it, as in an example context, we can see that 94% of accident is caused by fellow road users.

But to improve the system, further study is needed on road users' behavior with an AV, designing eHMI, and how the system can better understand the behavior of other road users.

6.2 Validation

We have discussed the major safety areas of an AV, refined them, and presented the critical safety concerns in the context of a level 4 AV in this article. And we highlighted the presence of the possible intervention of the human. Through this paper, we developed a framework where we can understand that installation of proper HMI can overcome the functional failure to at least some extent.

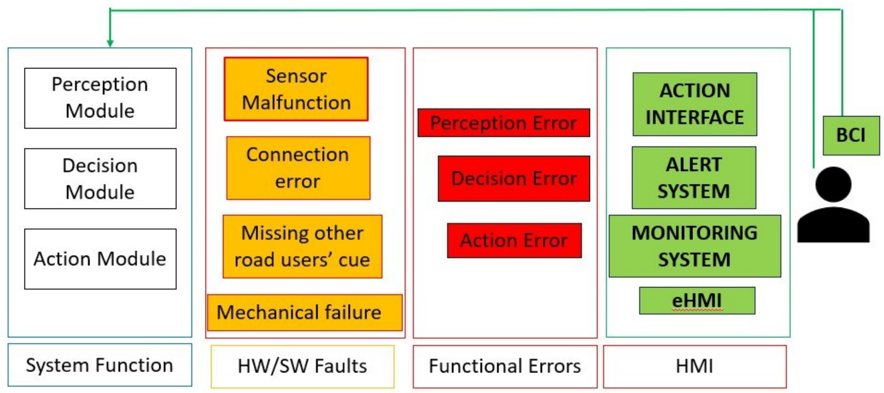

Figure 3. HMI in the loop to overcome ultimate functional errors to achieve functional safety.

As shown in Figure 3, we can see that different H/W and S/W malfunctions can lead to functional errors. In our paper, we emphasize the role of humans in the overall context and identify the factors that can play a crucial role in hazard mitigation.

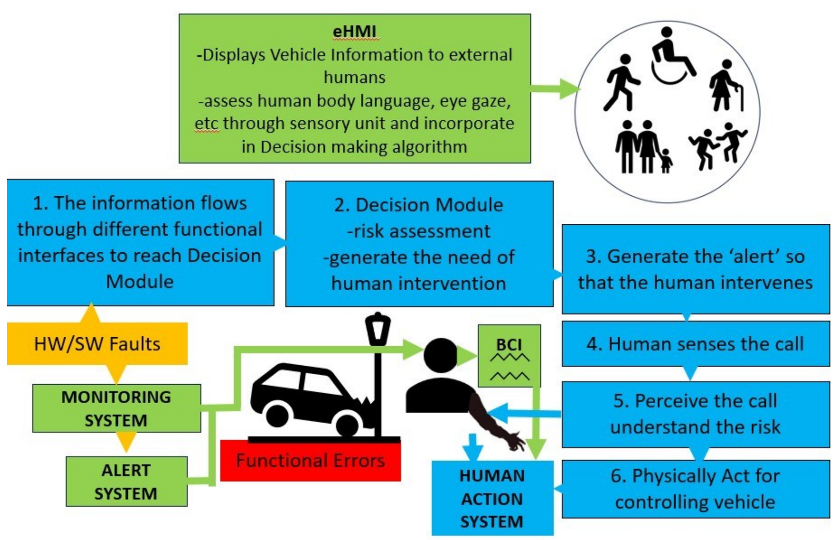

Figure 4. Schematic of a level 4 AV system with proper HMI installed in it

In Figure 4, we can observe the comparison of the traditional level 4 AV system (blue-boxed) and our proposed Human-centric design (green-boxed). We can see that there are several steps when the human intervenes based on the alert system, but when we incorporate an efficient HMI system, as we discussed throughout the paper, we can bypass steps

2, 3, 4, 5, and when we incorporate BCI technique, it also eliminates the step 6; which would save us some valuable time to save the hazard.

7. Conclusion

Level 4 AV includes the human in the loop of authority. This article addresses the challenge and opportunity and proposes ideas that will enable it to overcome the limitation of running in a restricted area. We discussed several steps of the Human Machine Interface, which includes the internal human passengers as well as the humans in external environments. Improving in all these areas will not only improve the status of level 4 AVs but also will be helpful for other AVs. Such as improving HMI for internal passengers will be helpful for level 3 AV, too. Designing efficient external HMI will improve level 5 AV. With this discussion, we aim to improve safety performance in several levels of Human Interactions, which is often overlooked by the system designers. In this study, we recommend putting more emphasis on designing Human Machine Interfaces for a level 4 AV.

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Biographies

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